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Discarded surrogates, modified traditions, welcome complements: The chequered careers of alternative technologies in Berlin's infrastructure systems

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Abstract

This article takes an historical perspective on current attempts to 'open up' established, centralized systems of urban infrastructure to alternative technologies designed to minimize resource use and environmental pollution. The process of introducing alternative technologies into, or alongside, centralized urban infrastructures is not a novel phenomenon, as is often assumed. The physical and institutional entrenchment of large technical systems for urban energy, water or sanitation services in industrialized countries in the late 19th and early 20th centuries did not close the door completely on alternatives. I investigate a number of alternative technologies used in Berlin in the interwar period (1920–1939), in order to reveal the rationales developed around each technology and the ways in which each emerged, disappeared and re-emerged or survived across highly diverse political regimes. The selection of cases is guided by the desire to illustrate three different phenomena of alternative technology diffusion (and exclusion) experienced in Berlin: (1) technologies promoted by early pioneers and discarded by their successors (waste-to-energy), (2) technologies modifying traditional practices that were at odds with modernized systems (wastewater reuse for agriculture) and (3) technologies co-existing alongside the dominant centralized system throughout the 20th century (cogeneration). The empirical findings are interpreted with reference to their contribution to scholarship on urban socio-technical transitions.

Keywords

Berlin, Germany, infrastructure, socio-technical transitions, technology

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Introduction

Debates today about the ‘transformation’, ‘reconfiguration’ or ‘transition’ of urban infrastructure systems place great store on alternative technologies. Founded on a critique of the limitations of established large technical systems (LTSs), both as a model for development in the Global South and as an answer to climate change and environmental degradation, considerable scholarly effort is being invested into exploring how entrenched, centralized LTSs for energy, water and wastewater services can be ‘opened up’ to allow the diffusion of a variety of alternative, largely small-scale, technologies. The aspiration underpinning this effort is that such technologies can help make urban infrastructure systems – traditionally regarded as inflexible, costly and resource inefficient – better suited to meet current and future challenges, whether resource scarcity and overuse, climate change, inequitable access or demographic change.

Research at the interface of urban studies, history of technology and science and technology studies has significantly advanced our understanding of the obduracy of existing urban infrastructure systems (Coutard et al., 2005; Hommels, 2005; Hughes, 1983; Melosi, 2000; Tarr and Dupuy, 1988), processes of infrastructure reconfiguration (Graham and Marvin, 2001; Guy et al., 2001; Summerton, 1994) and the potential of small-scale, alternative technologies in reordering entrenched LTSs (Geels, 2002; Geels and Kemp, 2007; Rohracher, 2007). While valuable knowledge has been generated on how alternative technologies rise from niche to mainstream and how LTSs become path dependent, little attention has been paid to those alternative technologies that did not make the mainstream (Melosi, 2005). There is still ‘a general tendency in historiography and contemporary depiction to rationalize actual social arrangements as somehow natural and inevitable, and to ignore alternatives which remained undeveloped’ (Russell, 1993: 34). The relevance of such technologies today lies not simply in understanding processes of technological exclusion in the past but also in examining how several of today’s ‘new’ technologies have historical roots. This article sets out to trace the chequered careers of some of these forgotten technologies of the past that are being resurrected and revamped today. It challenges the underlying assumption that today’s alternative technologies are inherently new and have no history.

I therefore take an historical perspective on current attempts to ‘open up’ established, centralized systems of urban infrastructure to alternative technologies intended to reduce use of natural resources, minimize environmental pollution and save costs. The process of introducing alternative technologies into, or alongside, centralized urban infrastructures is not a novel phenomenon. The physical and institutional entrenchment of LTSs for urban energy, water or sanitation services in industrialized countries in the late 19th and early 20th centuries did not close the door completely on alternative technologies. In view of the difficulties experienced today in reconfiguring urban infrastructures, it is worth exploring historical examples of (attempted) adaptation of LTSs involving innovative, small-scale technologies. I use this historical perspective, therefore, not to illustrate the path dependence of current urban configurations but rather to draw lessons from the past processes of infrastructure reconfiguration – both successful and unsuccessful – and how they were bound up in broader issues of urban (and national) change.

Here, I investigate a number of cases of alternative technologies from the fields of waste-to-energy, wastewater reuse and cogeneration used in Berlin, focusing on the interwar period (1920–1939). For each case, I explore the rationales developed around the technology and its emergence, disappearance and re-emergence or survival across highly diverse political regimes. My selection of cases is guided by a desire to illustrate three different phenomena of alternative technology diffusion (and exclusion) experienced in Berlin: (1) technologies promoted by early pioneers and discarded by their successors (waste-to-energy), (2) technologies modifying traditional practices at odds with modernized systems (wastewater reuse for agriculture) and (3) technologies co-existing alongside the dominant centralized system throughout the 20th century (cogeneration). I base my empirical analysis primarily on a systematic survey of the relevant professional journals published in Germany on energy (electricity, heating and gas), water and wastewater management over the period 1920–2010, focussing here on the interwar years. For my interpretations, I draw both on historical research of urban technology in Germany and wider scholarly debates on urban infrastructures in transition, today and in the past.

The next section of this article positions the study in the context of recent scholarship on socio-technical transitions and path dependency of urban infrastructure systems. Here, contemporary debates are reviewed in terms of their treatment of deviant technologies, to provide conceptual guidance for the article. The empirical section 'Careers of alternative technologies in Berlin' is subdivided into three categories of technological diffusion: (1) 'discarded surrogates', addressing the rise and fall of substitute fuels derived from waste; (2) 'modified traditions', referring to adaptations to established practices of wastewater use and (3) 'welcome complements', alluding to the cogeneration of heat from electricity generation. Each subsection traces the chequered careers of the alternative technologies from their emergence to today, setting the Berlin experiences in a broader context of technology and infrastructure development in Germany. In the interpretive section 'Interpreting chequered careers', the empirical findings are analysed in terms of different ways of conceptualizing path deviation in urban infrastructures, as identified in the section 'Conceptualizing deviant technologies in urban infrastructures'. The article concludes with a summary of the main findings and reflections on their relevance for today's attempts at urban infrastructure reconfiguration.

Conceptualizing deviant technologies in urban infrastructures

How is technological deviation from mainstream urban infrastructure configurations addressed in the existing literature? In the following section, I summarize the key strands of contemporary debate from the fields of science and technology studies and urban studies that are framing how we understand the socio-spatial dynamics of transitions in general and the part played by alternative technologies in particular.

The past fifteen years has seen a huge contribution to our understanding of continuity and change in complex socio-technical systems. These systems encompass 'a cluster of elements, including technology, regulations, user practices and markets, cultural meanings, infrastructure, maintenance networks and supply networks' (Geels, 2004). Early studies in the 'transitions' literature focussed on the historical development and diffusion of technological artefacts within socio-technical configurations, providing key insights into the political, cultural and social factors shaping their long-term trajectories (Geels, 2002, 2006). Here, I draw on Geels' Multi-Level Perspective (MLP) for explaining patterns of socio-technical evolution, addressing not only periods of emergence but also – significantly here – adaptation and disruption (Geels, 2002; Schot and Geels, 2008). The MLP comprises three 'levels', understood as heuristic concepts, rather than spatial categories. At the micro-level are niches, taken as protected spaces in which novel technologies can be developed. Niches provide a platform for innovations and experiments that can challenge the established socio-technical system. At the meso-level is the regime, comprising the rules, conventions and norms that constitute and regulate an incumbent socio-technical configuration. The regime imposes a degree of epistemic closure and path dependency around the dominant system, resisting radical change. At the macro-level is the landscape, understood as the broader economic trends, political cultures, social movements and environmental conditions that frame socio-technical systems. When elements of this 'landscape' change radically, they can destabilize established socio-technical configurations and thus prompt change. The particular value of the MLP framework lies in exploring and explaining the interactions that take place between these three levels. Transitions, understood as shifts from one relatively stable socio-technical configuration to another, result from interactions between the different levels of landscape, regime and niche. The MLP framework has been applied to interpret a wide variety of development trajectories, including technologies addressed in this article, such as biogas (Geels and Raven, 2006; Raven and Geels, 2010) and combined heat-and-power technologies (Raven and Verbong, 2007). Of particular relevance to this article are the findings on processes of transition pathways that go beyond technological substitution, involving the co-evolution of multiple technologies (Schot and Geels, 2008), the hybridization of different technologies (Geels, 2002) and the non-linearity of technological trajectories (Geels and Raven, 2006; Suurs et al., 2010).

Despite widespread acknowledgement of its contribution to scholarship on socio-technical transitions, the MLP framework has received considerable criticism, particularly from the fields of human geography and urban studies. In general terms, the criticism levelled at the transitions literature is that it pays too much attention to technological artefacts and elite actors and too little attention to socio-spatial contexts and power relations in the shaping of socio-technical transitions (Coenen et al., 2012; Lawhon and Murphy, 2011). This translates into complaints that the MLP framework overemphasizes the role of niches as incubators of change, downplaying the importance of regimes in enabling – as well as hindering – transitions and overlooking the variety of transition pathways that can coexist in any one context (Hodson and Marvin, 2010; Maassen, 2012; Smith et al., 2005).

Human geographers have accused the MLP framework of being 'geographically naïve' in the way it conceives of space, scale and place (Lawhon and Murphy, 2011: 360). Specifically, the criticisms are that the transitions literature does not consider or explain spatial variety and disparities, fails to ground transitions in specific territorial contexts, focuses primarily on national scales of action, is founded on developed country's experiences and – despite the multi-level terminology – says little about how different geographical scales interact in socio-technical transitions (Coenen et al., 2012; Coenen and Truffer, 2012). Others have highlighted the absence of cities in the MLP framework, despite the key role they play in socio-technical transitions (Bulkeley et al., 2011; Coutard and Rutherford, 2011; Frantzeskaki et al., in press; Hodson and Marvin, 2009, 2010). These authors are exploring ways of understanding how 'the urban' works in transitions, for instance, in terms of cities responding to national transitions, providing locales for niche experimentation, encompassing diverse visions of transition, organizing relationships between local actors, translating global pressures into urban practices or coping with the physical embeddedness of urban infrastructures. From this perspective, studying deviant technologies requires connecting socio-technical trajectories to the multiple geographies that shape and are shaped by urban infrastructures (Moss, 2014).

Unlike early transitions research, the recent literature from human geography and urban studies is based on analyses of ongoing transitions, rather than the reconstruction of historical developments. Looking across this body of work, one could be forgiven for assuming that the history of socio-technical transitions has been conclusively studied, so strongly are historical trajectories associated with the original transitions literature. However, the study of the past transitions could benefit from applying to historical analysis the conceptual ideas currently being formulated by human geographers. This should result in a more nuanced understanding of the socio-spatial dynamics of transitions in the past and the roles played in them by alternative, or deviant, technologies.

Older studies by urban historians give an indication of the complex political, cultural, economic and social forces at work in moulding modern urban infrastructure systems (Melosi, 2000; Tarr and Dupuy, 1988). However, their focus was primarily on early phases of emergence and consolidation of today's LTSs for energy, water and sanitation services and not on the fortunes of alternative technologies that competed or coexisted with them. To explore the latter calls for ways of understanding transitions not simply in terms of the breakthrough of a dominant technology and the path dependency cultivated around it but also of processes of readjustment, non-linearity and co-evolution in socio-technical trajectories (Dolata, 2009; Joerges, 1999; Russell, 1993; Van Laak, 2005). The recent work by James Simmie (2012) on path creation, building on a typology of Streek and Thelen (2005), is helpful in conceptualizing socio-technical transitions not as a shift from one path to another but as an iterative, dynamic process characterized by three types of technology diffusion: displacement, layering and conversion (cf. Melosi, 2010). 'Displacement' refers to a dominant technology being superseded by a subordinate one but continuing to exist for some time afterwards. 'Layering' refers to the addition of a new technology, while previous technologies remain in use. 'Conversion' refers to the modification but not displacement of older technologies. I use these analytical categories to interpret my study of the chequered careers of alternative technologies in Berlin since the 1920s, a study framed by the recent scholarship on the socio-spatial dynamics of urban infrastructures described above. My goal is to illustrate how contemporary debates on the socio-spatial dynamics of urban infrastructures can be used in historical research and, subsequently, what lessons can be drawn from this research for studying current socio-technical transitions in cities.

Careers of alternative technologies in Berlin

Discarded surrogates: Waste-to-energy[1]

In February 2012, a ceremony was held in Berlin to launch the building of a state-of-the-art biogas plant by the city's own waste utility BSR (Berliner Stadtreinigung). The fermentation plant, now in production, has a capacity to process 60,000 tonnes of biodegradable waste into biogas, comprising 98 percent methane. Each year, 3.4 million m^3 of gas from this plant is fed, once purified, into the city's natural gas network (BSR, 2010). In conjunction with the new plant, BSR will increase the number of its gas-powered waste collection vehicles to 150, thereby saving 2.5 million litres of diesel per annum. This represents an annual reduction in CO_2 emissions of 4000–5000 tonnes. Announcing the planned plant in a press statement, BSR claimed, 'This project is setting new standards for Germany as a whole and will make a significant contribution to climate protection in the capital' (BSR, 2012). Besides the city's waste utility, its water/wastewater utility BWB (Berliner Wasserbetriebe) is also proud to be taking steps to produce biogas. In an official agreement concluded with the Berlin city-state government in July 2008, the company cited the recent conversion of five of its sewage treatment plants to produce biogas to drive on-site combined heat-and-power plants as a major contribution to climate protection. With this technology BWB is generating electricity and heating amounting to 115,000 megawatt hours per year, representing an annual CO_2 savings of 21,900 tonnes (Berliner Wasserbetriebe, 2008). Both utilities give the impression that we are today witnessing the application of a radical new technology not seen before. Within the memory of most Berliners, this is certainly the case.

If we cast back 80 years, however, the picture looks rather different. In many German cities in the 1930s, the production and use of biogas derived from waste or wastewater was prevalent on a surprising scale (Deublein and Steinhauser, 2011: 32). It was claimed at the time that the methane gas produced from wastewater alone amounted to some 15.5 million m^3 per year (Heilmann, 1937: 353). This was used to run heating systems at sewage treatment plants, to drive machinery and vehicles, for heating and lighting, as well as to feed into city gas networks. Methane gas stations for vehicles were in operation in Stuttgart, Halle, Pforzheim, Essen, Erfurt, Pößneck and Munich, and proved very cost-effective. Indicative of the diffusion of this technology was the existence of a national norm (DVGW 3200) regulating the construction of gas pumps for coal gas, biogas from wastewater and other gases (Heilmann, 1937).

Berlin was a pioneer of the technology, producing gas from its wastewater pre-treatment plant at Waßmannsdorf as early as 1927 (Langbein, 1927; Langbein and Kroll, 1931). This plant alone produced 1.85 million m^3 of biogas in 1929, used to serve the energy requirements of its own municipal wastewater utility; this figure represents over half of the amount that was produced at the new BSR plant in 2012 (see above). The director of the utility, Fritz Langbein, calculated at the time that if all of Berlin's six planned sewage treatment plants could produce biogas to the same degree, this would cover the gas consumption of 275,000 people (Langbein and Kroll, 1931: 476). Writing after the Nazi seizure of power, having left his post, Langbein remained an ardent supporter of the technology, demonstrating how the biogas derived from Germany's sewers and treatment plants could provide 130 million m^3 of methane per year – over 5 percent of the country's total gas production

(Langbein, 1936). Used as a substitute for petrol or diesel, this gas, he calculated, could fuel 10,000 cars and save 14 million Reichsmark. During the war, under conditions of severe fuel shortages, gas derived from wastewater became a significant vehicle fuel, although, as one expert wryly noted, the poor nutrition of the population had a negative impact on the gas production potential of wastewater (Imhoff, 1947: 67). After the war, there was no further reference to the technology in any of the professional journals or utility reports studied. It disappeared from view in Germany for the next 70 years.

Deriving biogas from wastewater was not the only form of waste-to-energy practised in the 1930s. Considerable effort was also made to extract and recycle fats and oils from wastewater for reuse as soap, lubrication or fuel. A survey conducted by the national association of municipal authorities (Deutscher Gemeindetag) of all German towns of over 10,000 inhabitants in 1936 revealed a wide range of practices of fat and oil extraction from wastewater (Heilmann, 1937). With the help of fat or grease separators installed in establishments with high levels of used fat, such as canteens, hotels, meat processing plants and hospitals, around 10,000 tonnes of fat was extracted and collected across Germany each year. The cities of Cologne, Duisburg-Hamborn, Aachen, Krefeld, Mühlheim/Ruhr, Mönchengladbach and Bonn were cited as being particularly active in this field. In Berlin, one company alone collected and processed fat and grease from some 500 restaurants and 2000 butchers, as well as 50 canteens, 20 barracks and 35 hospitals (Heilmann, 1937: 323; Pallasch, 1937: 336). Once purified, the fat was used primarily for soap and industrial lubricants but also as a fuel substitute. It was estimated, however, that the costs of collecting and treating the used fat were twice as high as the income generated by its reuse. For this reason, those responsible in the wastewater utilities were pressing for the installation of fat separators to be made mandatory for all major waste fat producers, arguing that the investment would save on the considerable costs to the utility of removing solidified fat from blocked sewers (Heilmann, 1937).

Used motor oils were also extracted from wastewater, refined and subsequently reused as fuel or lubricant. Berlin's wastewater utility operated a local collection system for used oils (petrol, diesel, turpentine, lubricating oil) at 8500 garages across the city (Pallasch, 1937). The purified oils were then used by the utility itself, for instance, as fuels for its own vehicle fleet. In contrast to solid fat collection, the financial savings made here covered most of the costs incurred, including all costs for the collection vehicles and local separation appliances, as well as those of running the purification plant. Only the running costs of the collection itself needed subsidizing by the utility.

As with the extraction of biogas, these technologies for recycling fats and oils were not pursued after the war. They re-emerged on the agenda publicly in 2008 in the climate protection agreement between the Berlin water utility and the city-state government (Berliner Wasserbetriebe, 2008). Here, among the list of measures the utility is planning to implement in the future, are two proposals for recycling waste fats as energy sources. The first is to substitute the heating oil to fire sludge incineration plants with used fats extracted from wastewater, primarily via fat separators in restaurants. The second is to ferment used fat with wastewater sludge to produce a substitute for natural gas. It is estimated that, when introduced, these technologies will reduce CO_2 emissions each year by ca. 6000 and 1000 tonnes, respectively. In both cases, experiments and tests are currently being conducted by the utility.

Modified traditions: Wastewater reuse for agriculture

If technologies for deriving energy from wastewater and solid wastes represented a radical departure from previous practices in the 1930s, using treated wastewater to increase agricultural production was a modification of a long-standing tradition of wastewater treatment. Since the 1870s, irrigated farms had played a key role in Berlin's centralized system of wastewater collection, transportation and disposal, devised by James Hobrecht (Bärthel, 2006b; Mohajeri, 2005; Tepasse, 2006). Via a radial network of huge sewers, wastewater was pumped from the city to surrounding rural areas, where it was used – untreated – to irrigate farmland mostly belonging to the city. In the early years, this technology proved effective in vastly improving public hygiene in Berlin but also in enabling profitable agricultural production on low-grade land with the additional nutrients and water. Several other European cities, such as Paris, did the same (Barles, 2014; Védry et al., 2001).

By the 1920s, however, the huge increase in the quantity and toxicity of wastewater from the growing capital was generating massive problems of overload on these irrigated farms. The land had become heavily contaminated, undermining consumer confidence in agricultural produce from the farms, and excess wastewater was proving detrimental for crop growth. By the 1930s, over a third of the wastewater arriving at the farms was being redirected straight into the neighbouring river without any soil filtration at all (Weise, 1934). The response of the wastewater utility and authorities alike was to build sewage treatment plants on the sites of the farms, with the long-term vision of departing entirely from irrigation technology (Hahn, 1928; Langbein, 1930; Weise, 1934; cf. Bärthel, 2006b; Mohajeri, 2005; Tepasse, 2006). In 1931, the first sewage treatment plant was built at Stahnsdorf, to the south of Berlin. Others were to follow during the 1930s (Mohajeri, 2005: 233–257).

What might appear at first sight to be a simple shift from one technology to another, rendered smoother by the continued reliance on Hobrecht's radial system to transport the wastewater to the new treatment plants, proved highly controversial in practice (Seeger, 1999). The owners and tenants of the irrigated farms, as well as market traders, had vested interests in continuing agricultural production on the sites, despite the problems encountered (Barles, 2014; Oldenziel and Weber, 2013). In addition, following the Nazi seizure of power in 1933, an increasingly vocal community of sanitary engineers, nutrition experts and urban planners saw it as their national duty to prioritize food production over wastewater treatment. In the words of Berlin's responsible councillor at the time,

> Whereas earlier the task was to dispose of wastewater adequately and efficiently, today attention is focused on how to derive the greatest economic benefit for the country from it. (Kölzow, 1935: 108, translation by author)

Berlin's leading sanitary engineers, while pursuing their plans for constructing treatment plants, were at the same time exploring ways of optimizing food production from their irrigated farms (Kölzow, 1935; Langbein, 1936; Weise, 1934). In tune with Nazi ideology, they argued that wastewater was a valuable source of nutrients for food production that should not go wasted. They were also keen to highlight other benefits of reusing wastewater, such as reducing Germany's dependency on imported artificial fertilizers, maintaining groundwater tables and securing the long-term water supply. The underlying military agenda of recycling wastewater to secure food production was made quite explicit by a leading official in the Berlin city administration as early as 1934:

> We need to be aware that our neighbours, armed to the teeth, are in a position today to at any time destroy a large part of our crops, especially from the air, using fire, poison or explosives. … Under these circumstances we should be in no doubt that everything must be done in future to retain the nutrients in wastewater in order to use them to increase crop productivity. (Weise, 1934: 250, translation by author)

During the war, avoiding waste and reusing natural resources in wastewater became an obsession for many of Germany's key sanitary engineers (e.g. Heilmann, 1941).

Controversy continued, however, over whether treated or raw sewage should be used for agricultural production. This dispute was played out in the professional journals throughout the 1930s and during the war. Many leading engineers, such as Karl Imhoff and Otto Pallasch, were strictly opposed to using untreated wastewater for reasons of hygiene, arguing for the use of biologically treated wastewater for irrigation to produce crops (Heilmann, 1941). In contrast, Adolf Heilmann, editor-in-chief of the sanitation journal *Gesundheitsingenieur* and a Nazi party member, was in favour of only modest pre-treatment – in the form of basic sludge removal – prior to irrigation, arguing that any further treatment would significantly reduce the amount of nutrients and, thereby, the agricultural value of the wastewater, as well as increasing costs (Heilmann, 1941: 359). In practice, the use of untreated wastewater for agricultural production across Germany created major environmental problems. These were only belatedly addressed with Reich and Prussian regulations, which continued to prioritize wastewater reuse over disposal, playing down the risks to public health and water quality (Imhoff, 1947).

After the war, sanitary engineers were keen to distance themselves from wastewater recycling technologies. Imhoff, for instance, came out strongly against using even treated wastewater for irrigation purposes, something he had promoted in the 1930s (Imhoff, 1947). In Berlin, the plan to replace irrigated farms with sewage treatment plants was pursued with greater intensity as the city's post-war economy recovered (Hünerberg, 1968). This was particularly the case in West Berlin, keen to minimize dependency on East Germany by building an inner-city treatment plant at Ruhleben and phase out wastewater irrigation at its Karolinenhöhe site (Moss, 2009). As the irrigated farms were taken out of active use, there was no mention by any of the leading figures of the need to reuse the nutrients and water resources contained in wastewater (e.g. Cohrs, 1957; Hünerberg, 1968). Wastewater recycling was, like the waste-to-energy technologies, effectively written out of the city's history.

This remained the case until the early 1990s, following the reunification of Germany and Berlin. At this point, predictions of a water supply crisis in the Berlin region resulting from anticipated rapid growth spawned renewed scientific and policy interest in novel approaches to recycle water in the region (Moss, 2000). The city's water and wastewater utility, BWB, devised a plan to use 11.5 million m^3 of treated wastewater from its Ruhleben plant on its former irrigation farm at Karolinenhöhe (Schulze, 1993).

The purpose of this technology was not to maximize agricultural production, as it had been in the 1930s, but to replenish groundwater levels, prevent erosion of the contaminated soil, protect the unique landscape features and to maintain some traditional horticultural practices on-site. The plan was never implemented, but lived on as an option for groundwater replenishment. Today, interest in recycling wastewater is rising on the global agenda (Lazarova and Bahri, 2005). It is also re-emerging among water resource managers in the Berlin region. Concerns over the consequences of climate change for the region's water balance, the waste of valuable nutrients and the potential degradation of formerly irrigated farms are creating new pressure to revisit wastewater recycling technologies (Nölting et al., 2015). These are once again challenging some of the assumptions and logics underpinning the established, centralized system of wastewater collection, treatment and disposal in watercourses.

Welcome complements: Cogeneration

The case of cogeneration in Berlin is indicative of a technology that developed alongside the dominant LTS of centralized electricity generation yet managed to survive – and to some extent flourish – in various forms across the 20th century. Cogeneration – the combined generation of heat and power – was originally developed for commercial use in the 1870s in the United States and subsequently spread to Europe (Summerton, 1992; Ulloa, 2007). The technology was first applied in Berlin in 1912 to supply heat to the town hall of Charlottenburg from a neighbouring power station (Varchmin and Schubert, 1988). Berlin's first commercially run cogeneration plant was built in 1926 in Charlottenburg, using steam for heating, and the second a year later in Steglitz, using hot water (Bärthel, 2006a; Tepasse, 2006: 82–87). The principal arguments for cogeneration at the time were to improve air quality in the city by substituting coal-fired heating in households and businesses and to reduce the traffic needed to transport coal.

In Germany as a whole, the trend in electricity provision during the 1920s and early 1930s was towards the centralization and nationalization of generating capacity and long-distance transmission (Bleicher, 2007: 87–108; Hellige, 1986; Hughes, 1983: 313–319). Large-scale, interconnected transmission and distribution systems were to ensure a reliable source of electricity to meet rapidly increasing demand. This centralization trend has been criticized as a lost opportunity for decentralized energy technologies, such as cogeneration, which had already demonstrated their feasibility (Schott, 2008: 186). Following the Nazi seizure of power in 1933, many urban energy planners expected the new regime would reverse this process of centralization, pinning their hopes on the anti-capitalist and municipal wings within the National Socialist party (Moss, 2014). For the first two years of Nazi rule, these aspirations appeared justified, as district heating boomed. In Berlin, Erich Schulz, a leading figure in the city's electricity utility, Bewag, made a name for himself promoting 'combined energy management' for urban centres, saving energy and creating jobs *inter alia* with block-type combined heat-and-power plants (Hellige, 1986: 143–145; Varchmin and Schubert, 1988: 13). The Energy Act of 1935, however, set the process of centralization back on course (Hellige, 1986). It established a favourable legal framework for investment in large power plants serving long-distance, high-voltage supply networks. Many small municipal energy utilities were squeezed out of the market. Cogeneration proved difficult to maintain under the new legal provisions, despite its popularity among senior Nazi figures, such as Fritz Todt, the Inspector General for Energy and Water (Hellige, 1986: 145). Nevertheless, Berlin's power utility Bewag managed to dramatically increase the heating capacity of its cogeneration network by 1939 (Bublitz 1984: 442).

After the war, cogeneration experienced a revival in Berlin (Tepasse, 2006: 166–185), as in other European cities (Raven and Verbong 2007; Summerton, 1992). The power utility Bewag used the opportunity of urban reconstruction to extend its district heating systems substantially, combining local networks of neighbouring heat-and-power plants into larger units covering the central city area (Bublitz, 1984; Varchmin and Schubert, 1988). By 1968, capacity for heating from cogeneration had increased in West Berlin ninefold over pre-war levels for the whole city (Bublitz, 1984: 443). By 1984, the figure was to double again, making it the largest combined heat-and-power network of any West European city (Müller, 1987). Over the years, the decentralized technology of district heating became an integral part of the city's energy supply, with a length of 396 km and an output of over 15,000 terajoules of heat in 1988/1989 (Schmidt, 1990: 114). At the time of reunification in 1990, 27 percent of the city's total housing stock was served by district heating (Tepasse, 2006: 181). Cogeneration accounted for approximately 75 percent of the district heating produced in West Berlin (Von Grot, 1987) but only a small proportion of that in East Berlin.

As district heating grew in West Berlin, so did criticism from environmentalists that on such a large-scale it was inefficient and inflexible, despite cogeneration. District heating, a niche technology in the 1920s, found itself being compared unfavourably with the latest niche heating technology: block-type combined heat-and-power plants. During the 1980s, a dispute emerged between proponents of large-scale district heating and small-scale cogeneration for individual buildings or housing blocks (Varchmin and Schubert, 1988: 18–19). An official commission in 1985 recommended the construction of a large number of gas-fired block-type cogeneration plants across the city for reasons of energy efficiency. Several were installed, but fewer than in many other cities in West Germany, owing to the relatively wide diffusion of district heating. More recently, competition between the two technologies has received a fresh twist in the wake of the liberalization of the electricity sector and the sale of Bewag to the Swedish energy utility Vattenfall. Several of the large cogeneration plants in West Berlin have since been closed down because the electricity they produced was too expensive (Moss and Francesch-Huidobro, 2016). Their closure has opened up new opportunities for block-type and mini heating systems.

Interpreting chequered careers

In what ways can the empirical findings of this article contribute to ongoing debates on urban infrastructure systems in transition? How far do the chequered careers of these alternative technologies in Berlin substantiate or challenge the various approaches to conceptualizing the socio-spatial dynamics of urban infrastructures found in the literature?

The three stories of alternative technologies recounted above do not fit older conceptualizations of socio-technical change. All three innovations should have disappeared completely once they had lost the battle for supremacy against the dominant technology.

While none of them came close to substituting the established socio-technical configuration, they all managed to coexist with their respective LTSs in Berlin for at least a decade (waste-to-energy, wastewater recycling), if not permanently (combined heat-and-power). This coexistence was, moreover, not one of reluctant toleration by the key actors of the socio-technical regime under political duress but was actively encouraged by them. All of the alternative technologies discussed here were promoted and managed by the municipal utilities responsible for the city's main infrastructure systems. Leading figures in these utilities and the city administration were pioneers in implementing these alternative technologies, even while being the defenders of the dominant LTSs. The socio-technical regime was itself a driver of innovation. The alternative technologies could coexist alongside the LTSs because they were deemed, for a while, to complement the dominant socio-technical configuration. In the terminology of transitions theory, they provide good illustrations of the *co-evolution* of multiple technological pathways. For path creation theory, they offer examples of *layering*, the new technologies emerging alongside existing ones. The new physical infrastructures required to enable waste-to-energy conversion, for example, were connected to the established sanitation system but did not alter its mode of operation.

Second, the three cases reveal instances of technological *hybridization* (transitions theory) or *conversion* (path theory). This refers to situations where a new technology does not just coexist alongside or within a LTS but actually modifies it. Examples of this kind illustrate the adaptability of seemingly obdurate socio-technical configurations. The case of combined heat-and-power generation in Berlin can be interpreted in this way. Prior to cogeneration, in the early 1920s, power and heat generation were distinct socio-technical systems. The subsequent viability and desirability of cogeneration in the city brought the two closer together, requiring significant adaptations. Cogeneration plants had to be built in close proximity to areas of high heating demand, and electricity generation had to accommodate demand curves for heating as well as power.

Third, the Berlin experience is rich with illustrations of the *non-linearity* of socio-technical transitions. The most distinctive feature of my story is that many alternative technologies emerged, were incorporated within a socio-technical configuration, then were discarded, only to reappear decades later in a modernized form. In Berlin, this applied to new technologies for using biogas and recycling fats and oils, as well as to an old technology, for reusing wastewater, that regained popularity in the 1930s but was dropped after the war. This points to phases of openness, during which alternative or supplementary technologies are encouraged, and phases of closure, when they are rejected or resisted. Closure can emerge out of a perceived incompatibility between the alternative and entrenched system, as the controversy over wastewater reuse in agriculture during the 1930s illustrates. It can also, though, emerge out of shifting political contexts, as I will explore in more detail below. The challenges confronting cogeneration today indicate that a technology that has survived and flourished across four different political regimes can nevertheless run into severe difficulties as a result of changes in the political economy, in this case the liberalization of the electricity market.

Non-linearity can be seen not only in the presence or absence of a technology in a socio-technical configuration but also in the shifting purposes attributed to it. Thus, motives for reusing wastewater in Berlin have altered radically over the past century, from relieving the city of its waste in the early 20th century, via reducing German dependence on food imports during the Nazi era, to enhancing degraded landscapes today.

Finding rich evidence of co-evolution, hybridization and non-linearity is valuable in substantiating research findings elsewhere on the messiness and contingency of socio-technical transitions. These categories have also proven helpful in looking across the cases to identify common phenomena. The empirical evidence suggests, however, that additional categories of ‘submersion’ and ‘re-assertion’ are required to describe those technologies that disappeared from the policy agenda and re-emerged subsequently in a modernized form.

What is still missing in my analysis so far, though, are explanations for why these alternative technologies experienced such chequered careers. How did these technologies become established as additions to existing urban infrastructure systems in the first place? What factors contributed to the disappearance of waste-to-energy and wastewater reuse technologies from infrastructure policy and practice following the war? How was it possible for cogeneration to survive diverse techno-political regimes? What is enabling the re-emergence of these technologies today?

Although there may be many other ways of responding to these questions, I choose to focus on the socio-spatial contexts and dynamics shaping Berlin’s infrastructure systems. It is through a geographical lens encompassing issues of space, place and scale that I tentatively seek explanations for the chequered careers of the technologies studied. In explaining the emergence, disappearance, persistence and re-emergence of alternative technologies in Berlin, I look to the role played by urban politics, local contextual factors and scalar relations between the city and the nation state. I should point out, however, that in the absence of rich primary source material and any substantial secondary literature on these technologies in Berlin, the following should be treated as one possible reading of the available data, rather than a definitive interpretation.

The emergence of the alternative technologies addressed here cannot be attributed primarily to a national policy shift launched by the National Socialists. They all originated prior to the Nazi seizure of power. As I have noted, Berlin’s first commercial heat-and-power plant dated to 1926. Biogas was being produced at the city’s wastewater treatment plant at Waßmannsdorf in 1927. Ideas about using treated wastewater for agriculture, in the interest of reducing food imports and providing jobs for the unemployed, were being voiced during the Depression of 1929–1932. Together, these examples indicate not one but a number of contributory factors, ranging from a culture of innovation and technological prowess in the technical-scientific community to pressures of socio-economic hardship. What is distinctive, as I have noted above, is the prominent role played by Berlin’s municipal utilities and city government officials in promoting the technologies as part of their established LTSs.

However, the major push for these technologies came from the second four-year plan of the Nazi regime, introduced in October 1936 (Ludwig, 1974; Maier, 1996). This marked a radical rescaling of socio-technical configurations from the urban to the national scale, in which Berlin was increasingly required to serve the national interest. The national interest was defined in the plan as economic independence (autarky) for Germany within four years, to be achieved through a series of policies and measures to reduce foreign imports of raw materials. It was based on a memo written by Hitler himself, setting out its hidden military agenda: to put the German economy in a position to attack the Soviet Union (Ludwig, 1974: 161). The plan was widely publicized in engineering journals with powerful, emotive appeals to German engineers to rise to the call and contribute through their creativity and expertise to meeting the targets. These appeals were backed up with considerable funding and political support for technologies that could allow the substitution of imported raw materials, reduce resource use or recycle waste products (cf. Oldenziel and Weber, 2013; Saraiva and Wise, 2010). The support applied specifically to the waste-to-energy and wastewater reuse technologies described in this article (Mohajeri, 2005: 258–259). The powerful message underpinning the campaign was that these new technologies were serving the 'common good' of the German people. Compliant engineers could expect hitherto unknown freedoms in their efforts to contribute to a distinctly national cause (Maier, 1996: 260ff). The role of the city – as with all other social entities – became subjugated to the National Socialist project. To this end, all leading figures in Berlin's city government and its municipal utilities were replaced by supporters of the regime shortly after the Nazi seizure of power in 1933.

There are a number of possible explanations for the disappearance of alternative technologies after 1945, all of which have some degree of validity. Most straightforwardly, the technologies were not advanced enough to survive. Many engineers today take this line, arguing that such technologies were neither technically nor economically viable (Bärthel, 2006a, 2006b; Mohajeri, 2005; Tepasse, 2006). When the funding programmes were axed towards the end of the war and political support collapsed with the Nazi regime in 1945, the fundamental flaws of these technologies were revealed and they were consequently discarded. This view accords major significance to the inherent quality of a technology as the principal factor behind its diffusion and takes no consideration of spatial context.

A second explanation is that the path dependence of existing socio-technical regimes reasserted itself after 1945. On this line of argument, the dominant technological systems – whether for the centralized collection and disposal of wastewater or the national electricity grid – were never seriously challenged. Alternative technologies enjoyed temporary prominence in cities like Berlin, where experimentation was encouraged, but only insofar as they did not threaten the operational effectiveness and institutional arrangements of the LTSs. The re-assertion of the incumbent LTSs was buoyed culturally by a post-war consumer society in which human well-being and social status were increasingly associated with high levels of energy and resource use. Thrift and reuse were, for many, uncomfortably reminiscent of wartime austerity. This second explanation is much broader in scope than the first, considering not only the technology itself but also complex socio-technical configurations in particular locales.

A third explanation locates the key issues in circumstances peculiar to the post-war period in Germany. Because of the strong association between the technologies discussed here and the Nazi regime, the recycling technologies heralded under the four-year plan became a political liability after the war. Those engineers and others who had made careers in promoting alternative technologies in the 1930s were keen to dissociate themselves from them in post-war Germany. Their future careers depended on demonstrating that they, individually and as a profession, were returning to the fold of mainstream sanitary and energy engineering. The change is strongly evident in the professional journals published after 1945, which addressed solely conventional infrastructure technologies, and included no references to alternatives from the past or to the need for recycling or saving natural resources. A particularly revealing article by the leading sanitary engineer Karl Imhoff was published in 1947 as part of a report on wartime wastewater technologies written for the Field Information Agency; Technical (FIAT) Review of German Sciences (Imhoff, 1947).[2] In it, Imhoff distanced himself publicly from wartime research on wastewater technologies, in which he himself had been actively involved. He reserved particular criticism for the practice of land irrigation with (treated) wastewater for putting public health at risk and distracting attention from the more serious pollution problems caused by the armaments industry. Thus, the alternative technologies may have disappeared because they were tarnished with the brown brush of Nazism.

Such a view resonates with David Blackbourn's criticism of the 'Nazi taint', which has prevented to this day a differentiated analysis of ways of seeing landscape in German history because it is too easily caught up in racial, fascist and nationalist thought (Blackbourn, 2006: 18). For the same reason, we can suspect that Germany's early waste recycling technologies did not just disappear; they were – and still are, to some extent – deliberately ignored. Popular histories of Berlin's infrastructure written by engineers, planners and some academics avoid discussing those technologies promoted under the National Socialist regime (Bärthel, 2006a, 2006b; Mohajeri, 2005; cf. Seeger, 1999; Tepasse, 2006). The treatment of the Nazi period in these studies is extraordinary for its absence. If addressed at all, the period is portrayed in the briefest possible way, and as a political disaster that contributed nothing to the city's infrastructure systems except excessive demands (e.g. high energy needs, heavy pollution), aberrant technologies (e.g. waste-to-energy) and, ultimately, physical destruction via allied bombing (Mohajeri, 2005: 258–259). In the general course of technological progress, the Nazi period is widely regarded as an 'interruption' (Seeger, 1999: 55). No mention is made of the discourses and practices surrounding resource efficiency and reuse. The dismissive treatment of the Nazi period is indicative of a more deep-seated unwillingness to acknowledge the multiple ways in which technologies are inextricably bound up with political, social, economic and cultural contexts and contingent events. Here, we note strong parallels to Robert Proctor's work on the anti-tobacco campaign of the Nazis and what he terms 'agnotology', or the cultural production of ignorance, expressed in collective forms of post-war denial by the scientific community (Proctor, 1999; Proctor and Schiebinger, 2008).

The case of cogeneration represents an interesting contrast to the waste-to-energy and wastewater reuse technologies because it did survive the collapse of the Nazi regime and even flourished in West Berlin as a welcome complement to the city's power and heating systems. Why did this alternative technology prove persistent when the others studied here were discarded? One initial tentative explanation is that district heating in Berlin was more soundly established before the Nazi era and, given the centralization trend in national energy policy after 1935, was not actively promoted by the regime. Cogeneration was therefore immune to the 'Nazi taint' after the war. Beyond this, however, we can identify a number of other explanations, which all point to the importance of socio-spatial context in framing a technology's development trajectory. Physically, the combined heat-and-power plants had become part of the city's socio-technical regime for electricity provision well before the war, co-existing alongside more conventional technologies.

Power generation in the city was dependent on the material infrastructure of cogeneration. Institutionally, too, district heating was well protected, being operated by the city's monopoly power utility, Bewag. As the person in charge of heating at Bewag during the 1980s, Dietrich Bublitz, puts it,

> Urban heating was never at any time alien to Bewag. It was always integrated and fully adaptable to the needs of the company's overarching task of providing electricity. (Bublitz 1984: 447, translation by author)

Geopolitically, cogeneration proved especially valuable for West Berlin following political division in 1949. The pressing need to save on imports of coal from the West and to minimize dependence on energy sources from East Germany strengthened the case for a more efficient use of available energy resources (Moss, 2014). This issue of energy security gained added importance following the oil crisis in the 1970s, when district heating was expanded to replace oil heating. Environmentally, concerns over local air pollution and, subsequently, climate change provided powerful arguments in favour of district heating. Having survived the turbulence of Nazi dictatorship, wartime destruction and political division, Berlin's district heating system is being undermined today by the effects of liberalization and privatization. Shifts in the political economy of energy provision in Germany and the European Union are challenging the competitiveness of cogeneration in Berlin, resulting in the closure of several combined heat-and-power plants.

As the future for cogeneration in Berlin appears less secure, the prospects for waste-to-energy and wastewater recycling technologies are improving. The re-emergence of these alternative technologies today, after decades of neglect, can be attributed to complex interactions between international or national discourses and policies on environmental change on the one hand and local politics and practices of infrastructure management on the other hand. I can only touch on the gamut of global factors generating a more favourable environment for the re-emergence of the technologies addressed here (on biogas, see Negro and Hekkert 2008; Raven et al., 2008; on wastewater reuse, see Lazarova and Bahri 2005). First, policies are being introduced to promote renewable energy, recycling materials and energy conservation in the interests of environmental and climate protection. For example, the German Law for Renewable Energies of 2000 provided a boost to biogas production via subsidies for power generated from renewable sources (Deublein and Steinhauser, 2011: 35–36). Second, technological developments in Germany are increasingly influenced by global discourses on recycling and their applications worldwide. This applies, for instance, to the use of treated wastewater for irrigation in developing countries (Hamilton et al., 2007), the rapid expansion of biogas worldwide (Deublein and Steinhauser, 2011: 39ff) and the problems of excessive amounts of waste fats in sewers (Marvin and Medd, 2006). Third, utilities are increasingly aware of the importance of their 'green' image in the public eye.

These signals are being picked up, reinterpreted and pursued by actors of infrastructure in Berlin. The city's power, water and waste utilities have all entered into agreements with the Berlin city government to save natural resources and contribute to climate protection. They are also developing alternative technologies locally with a view to marketing them globally. Pressure from regulatory bodies to increase the quality of watercourses is encouraging the water/wastewater utility BWB to consider wastewater reuse technologies as a way of minimizing costly investment in more extensive wastewater treatment and of marketing phosphates extracted as a fertilizer. As with biogas and the recycling of used fats, we see here a combination of political pressures, economic incentives, market opportunities and environmental sensitivities, which are translating into local action in favour of alternative technologies.

Conclusion

There is a common assumption in policy and research circles that today's alternative technologies are something radically new. Using a number of examples from the fields of waste-to-energy, wastewater reuse and cogeneration developed and applied in and around Berlin during the interwar period, I have traced their chequered careers to the present, demonstrating how they coexisted with established, large-scale socio-technical systems, whether in conjunction or in competition. The history of these technologies is not linear and gradual but one marked by phases of emergence, disappearance, persistence and re-emergence. More importantly, these phases were not pre-determined by some inherent qualities or deficiencies of the technologies themselves but were the result of interactions within and beyond complex socio-technical configurations.

The trajectories of these deviant technologies are inadequately captured in terms of path dependency, the staple explanatory force of much past historical scholarship. The alternative technologies in Berlin certainly never supplanted the dominant socio-technical regime but neither did they disappear. Their continued existence – sometimes after long periods of hibernation – does not fit the narrative of one socio-technical path replacing another. Berlin's alternative technologies have had careers marked by unexpected flips, sudden reversals or adaptive continuity. In order to interpret these phenomena, I turned to contemporary studies of socio-technical transitions and urban infrastructures. In particular, I drew on concepts characterizing processes of co-evolution/layering, hybridization/conversion and non-linearity. I identified several examples of each of these processes across the three cases studied, thereby supporting the literature highlighting these dimensions of socio-technical transitions. For instance, the coexistence of new waste-to-energy infrastructures alongside older wastewater treatment plant is a fine illustration of layering. The emergent interdependency between combined heat-and-power generation and conventional coal-fired power stations offers an intriguing case of hybridization. The rise, fall and (later) resurrection of biogas from waste products and the recycling of used fats and oils are powerful portrayals of the non-linearity of socio-technical trajectories.

To the existing typology I would add – on the basis of the empirical evidence – the categories 'submersion' and 're-assertion' to describe those technologies that disappeared from the policy agenda and re-emerged in a modernized form to address new challenges. These technologies are not 'lost' alternatives, but rather ones that were intentionally discarded and subsequently ignored, or even repressed from collective memory. This practice of deliberate exclusion cannot be explained primarily in terms of dissatisfaction with the functionality or performance of the technologies. More significant is how they were perceived – and judged – by those responsible for their (non-)

implementation. The factors influencing these perceptions were varied and dynamic, prompting sometimes radical shifts in the appeal of individual technologies in professional circles. They ranged from concerns over resource security and environmental degradation to the geopolitics of a divided city, from the career aspirations of sanitary engineers to the racist-nationalist ideology of the Nazi regime. Later generations of engineers and planners have contributed to our ignorance of the roots of these technologies by reifying the modernist narrative surrounding conventional urban infrastructure systems. Alternative technologies that are seen to challenge the modernist narrative are generally dismissed as aberrations. They have been effectively written out of history, despite having played a significant role in past debates, as we saw for Berlin. The aversion against those technologies that were actively promoted by the Nazis represents a case of cultivated ignorance, which holds to this day.

While substantiating recent research on forms of non-conformity in socio-technical transitions, my study challenges a simplistic reading of the concepts of niche, regime and landscape in the transitions literature. A prime platform of innovation in each of my cases was, intriguingly, not the experimental niche but the socio-technical regime itself. The system managers – whether in the municipal utilities or the city government – were often the ones driving the alternative technologies, although they were primarily responsible for the dominant LTSs. This suggests that we need to beware of assuming *a priori* that a socio-technical regime is resistant to change. In addition, the massive interventions by Nazi elites in favour of alternative technologies in the interests of national autarky cannot be subsumed simply as a ‘favourable’ exogenous factor. ‘Landscape’ factors influencing transitions are not something ‘above’ socio-technical niches and regimes, but very much part of them: During the 1930s, individual engineers internalized the Nazi ideology to their own (initial) advantage.

My analysis of the socio-spatial factors affecting the emergence, disappearance, persistence and re-emergence of alternative technologies in Berlin contributes to recent work in human geography and urban studies in several ways. First, it provides an illustration of the multiple geographies at play in socio-technical transitions. The careers of Berlin’s alternative technologies described here were, as we have seen, shaped by a combination of physical geographies (e.g. the spatial range of its sewers or the non-availability of natural resources during wartime), environmental geographies (e.g. whether to dispose of wastewater on irrigation fields or into rivers), political geographies (e.g. the division of West and East Berlin) and institutional geographies (e.g. the responsibility of service provision by municipalities). Second, I draw particular attention to the importance of political conflict and power play at different spatial scales, from the city and city-region to the national and even international. At several stages in their career, alternative technologies served as symbols of Berlin’s technological prowess (e.g. biogas from waste products), a medium for implementing national government policy (e.g. resource autarky), bulwarks against geopolitical isolation (e.g. district heating networks) or expressions of local self-government (e.g. managed by municipal utilities). Third, I have emphasized the importance of a city’s (hidden) history of technological careers for understanding ongoing processes of socio-technical reconfiguration, building on a long tradition of valuable work on the connectivity between urbanization processes, urban governance and the emergence of modern urban infrastructures. By revealing the roots of today's alternative technologies, I have attempted to demonstrate the importance of acknowledging not only the existence of forerunners and earlier spatial contexts of application but also the selective construction at work in presenting past, present and future urban infrastructures, excluding some parts and highlighting others.

The lessons that can be drawn for today's attempts at infrastructure reconfiguration are wide-ranging and complex. Berlin's history of socio-technical transitions can reveal more than just the path dependencies of today's urban infrastructures. The Berlin story also highlights not only the importance of politics to socio-technical transitions but also how power relations work across niches, regimes and landscapes. The insidiousness of the Nazi regime lay precisely in its ability to transmit its racialist and militaristic ideology into the minds of engineers as a technological challenge in the national interest. This suggests that we need to pay greater attention in the future to how interests and power become bound up in the material form, institutional arrangements and symbolic value of urban infrastructure systems and how political shifts reverberate across these systems in diverse ways. Finally, the multiple geographies at play in the history of alternative technologies in Berlin – whether physical, environmental, political or institutional – point to promising avenues of research on the socio-spatiality of current transitions. Unpacking the complex scalar relations, local embeddedness and city politics that shape and are shaped by urban infrastructures is likely to reveal improved ways of understanding and informing socio-technical transitions today.

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Notes

1. An earlier version of this section will be published in Moss (in press).
2. The Field Information Agency; Technical (FIAT) Review of German Science (reports) covers the period of years 1939–1946. It was compiled by German scientists with the assistance of the Military Governments of the British, French and American zones of occupied Germany.

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